APPLICATION UNDER UNITED STATES PATENT LAWS

Invention: METHODS AND DEVICES RELATED TO ELECTRODE PADS FOR
P-TYPE GROUP III NITRIDE COMPOUND SEMICONDUCTORS

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This is a:

[   ] Provisional Application

[XX] Regular Utility Application

[   ] Continuing Application

[   ] PCT National Phase Application

[   ] Design Application

[   ] Reissue Application

[   ] Plant Application

SPECIFICATION

CDC-100   9 96

METHODS AND DEVICES RELATED TO ELECTRODE PADS
FOR P-TYPE GROUP III NITRIDE COMPOUND SEMICONDUCTORS

BACKGROUND OF THE INVENTION

Field of the Invention

The present invention relates to electrode pads for a Group III nitride compound semiconductor having p-type conduction, a Group III nitride compound semiconductor device having this type of electrode pads, and methods of forming these electrode pads. In particular, the invention relates to electrode pads for a Group III nitride compound semiconductor having p-type conduction with improved adhesive strength and luminous efficiency. Further, the invention relates to a method for forming the electrode pads and preventing the side etching of a protection film when forming a window through the protection film by etching.

Description of Background Information

Conventionally, gold (Au) deposited on a surface of a p-type conductive gallium nitride (GaN) layer is used as an electrode. Because the adhesive strength between the Au layer and the GaN layer is weak, an electrode layer made of Au peels easily away from the GaN layer during alloying processes performed on the GaN layer.

As a means to improve the adhesive strength, an electrode with a double layer structure is employed interposing a nickel (Ni) layer between the Au electrode layer and the GaN layer.

The electrode made of the Ni layer and the Au layer formed thereon also functions as an electrode pad for wire

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bonding. As shown in FIG. 5A, the semiconductor device is
uniformly covered with a protection layer 20 to protect the
surface of the device. As shown in FIGS. 5A and 5B, mask
layers 21 are formed exposing some part of the protection
layer 20 over the Au layer. The exposed portion of the
protection layer 20 is removed by etching to form a window
20a. A lead wire is bounded to the electrode pad of the
window 20a.

However, because the adhesive strength between the Au
layer and the protection layer 20 is weak, etching liquid
penetrates between them. Thus, some part of the protection
layer 20, even a part which is under the mask layers 21 are
removed as shown in FIG. 5B. As a result, forming the
window 20a as planned is difficult.

SUMMARY OF THE INVENTION

An object of the present invention is, therefore, to
obtain an electrode pad strongly adhered to respective the
Group III nitride compound semiconductor and the protection
film.

Another object of the present invention is to improve
ohmic characteristic of the electrode layer. The ohmic
characteristic is defined as figure of volt-ampere (VI)
characteristic. Improved ohmic characteristic includes
fine linearity of VI characteristic and small contact
resistance.

Further object of the present invention is to improve
adhesive strength between the electrode layer and the Group
III nitride compound semiconductor.

Further object of the present invention is to improve
luminous intensity achieved by improvement in effective

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current density.

The Group III nitride compound semiconductor satisfies the formula $Al_xGa_yIn_{1-x-y}N$, wherein $0 \leq x \leq 1$, $0 \leq y \leq 1$, and $0 \leq x+y \leq 1$.

A first aspect of the present invention is directed to an electrode pad for a Group III nitride compound semiconductor having a p-type conduction. The electrode pad successively includes a first metal layer formed on one of the semiconductor layer and an electrode layer, a second metal layer formed on the first metal layer, and a third metal layer formed on the second metal layer. A protection film is formed covering over the surface of the device and exposing a central portion of the third metal layer. The second metal layer is made of gold (Au). A composite element of the first metal layer has an ionization potential lower than gold (Au), and a composite element of the third metal layer has adhesiveness to the protection film stronger than gold (Au).

The composite element of the first metal layer should preferably be at least one of nickel (Ni), iron (Fe), copper (Cu), chromium (Cr), tantalum (Ta), vanadium (V), manganese (Mn), aluminum (Al), and silver (Ag). The composite element of the third metal layer should preferably be at least one of aluminum (Al), nickel (Ni), and titanium (Ti). Further, the protection film should preferably be made of silicon oxide e.g.. SiO, SiO_2. and Si_2O_3 or silicon nitride e.g., SiN_2 and Si_3N_4. The most preferable combination of the composite metals for the electrode pad is the first metal layer comprising nickel (Ni), the second metal layer comprising gold (Au), and the third metal layer comprising aluminum (Al).

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The electrode pad with the above identified structure
may be formed directly on the semiconductor layer or on the
electrode layer formed on the semiconductor layer depending
on purposes. An LED, for example, requires an electric
current to flow through a semiconductor layer vertically
and uniformly for increasing an emission area. In this
case, an electrode layer formed on the semiconductor layer
is fairly wider than the electrode pad.

In order to improve an ohmic characteristic including
lowering contact resistance, and increase the adhesive
strength between the electrode layer and the semiconductor
layer, the electrode layer should preferably have a
multi-layer structure at least comprising a first electrode
layer formed on the semiconductor layer and a second
electrode layer formed on the first electrode layer. The
first electrode layer comprises an element that has an
ionization potential that is lower than that of the second
electrode layer and the second electrode layer comprises an
element which has an ohmic characteristic to the
semiconductor layer better than that of the first electrode
layer. Heat treatment for alloying process of the
semiconductor makes the element of the second electrode
layer distributed more deeply into the semiconductor layer
than that of the first electrode layer. Namely, the order
of distribution of the elements is reversed by heat
treatment. Before heat treatment, the element of the
second electrode layer exists on that of the first
electrode layer. After heat treatment, however, the
element of the second electrode layer exists below that of
the first electrode layer. The discovery of this phenomena
is another aspect of the present invention.

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The reversal of element distribution, however, does not occur at some portion of the electrode layer which is covered with an electrode pad. Accordingly, the portion of the electrode layer under the electrode pad has a poor ohmic characteristic i.e., a high contact resistance, and thus, flow of electric current detours around this portion. This structure contributes to an improved luminous efficiency. Since emitted light under non-transparent electrode pad cannot be emitted outside, utilizing this structure enables the electric current to flow to effective portions of a device so that emitted light can extend outside. Consequently, enlarging effective current density improves luminous efficiency. In view of the improved luminous efficiency, the protection film is not necessary and the electrode pad may be formed in a double or a single layer structure.

The first electrode layer should preferably be made of at least one of nickel (Ni), iron (Fe), copper (Cu), chromium (Cr), tantalum (Ta), vanadium (V), manganese (Mn), aluminum (Al), and silver (Ag), and the second electrode layer be at least one of palladium (Pd), gold (Au), iridium (Ir), and platinum (Pt). The most preferable combination of the composite metals of the electrode layer is the first electrode layer comprising nickel (Ni) and the second electrode layer comprising gold (Au). In this case, heat treatment reverses the relative positions of Ni and Au. Gold (Au) moves deeper with respect to the semiconductor layer than nickel (Ni). Heat treatment may preferably be carried out at a temperature generally ranging from 400 °C to 700 °C.

As another aspect of the present invention, the Group

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III nitride compound semiconductor device using the above
described electrode pads includes one of a light-emitting
diode (LED), a laser diode (LD), and a transistor.

Because the composite metal of the first metal layer
has an ionization potential that is lower than that of a
second metal electrode layer, a strong adhesive strength of
the metal layer to the semiconductor can be maintained. A
protection film formed on the third metal layer covering
the sides of the first, second, and third metal layers has
a strong adhesive strength to the third metal layer.
Accordingly, etching the inner sides of the protection film
can be prevented during an etching process to remove some
portion of the protection film. As a result, the
protection film can function as intended.

Further, the electrode pad shields the effect of heat
treatment to the layers thereunder. The portion of the
electrode layer under the electrode pad does not undergo a
reversal in its distribution of elements. Accordingly, the
contact resistance of some portion of the electrode layer
which is under the electrode pad is high, and thus,
electric current detours this portion and flows into other
parts of the electrode layer. Consequently, luminous
efficiency of the device is improved by increasing
effective current density for emission.

The other portion of the electrode layer which is not
covered with the electrode pad undergoes a reversal in its
distribution of elements. Because the element of the first
electrode layer has an ionization potential lower than that
of the second electrode layer, the first electrode layer
has a greater adhesive strength than the second electrode
layer. The second electrode layer, which has a work

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function larger than that of the first electrode layer.
That is, the second electrode layer has a higher ionization
potential than that of the first electrode layer, and has a
better ohmic characteristic to the semiconductor layer.
Providing a heat treatment on the electrode layer causes
the element of the first electrode layer to move to the
surface of the second electrode layer. In particular, the
element of the second electrode layer penetrates through
the first electrode layer and significantly into the
semiconductor layer. A larger portion of the element of
the first electrode layer moves and distributes on the
surface of the electrode layer. This reversal of the
distribution of the elements of the first and the second
electrode layers improves both the adhesive strength and
the ohmic characteristic between the electrode layer and
the semiconductor layer. Particularly, when nickel (Ni) is
used as the composite material of the first electrode layer
and gold (Au) as that of the second electrode layer, Au
penetrates through the Ni first electrode layer. Thus, the
ohmic characteristic is improved, i.e., contact resistance
is lowered, by using gold (Au) and the adhesive strength
between the electrode layer to the semiconductor layer is
maintained by using nickel (Ni). On the other hand, some
portion of the electrode layer which is under the electrode
pad has a high contact resistance, but has enough adhesive
strength because Ni remains on the surface of the
semiconductor layer.

A Group III nitride compound semiconductor device
having an electrode structure as described above improves
its device characteristics such as reduction of both
applied voltage and contact resistivity and improvement in

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its reliability.   In addition, when the electrode described above is used for an LED and an LD, emission efficiency is improved.

The above and other objects, features, advantages, and characteristics of the present invention are further described in the following detailed description with reference to the accompanying drawings by way of non-limiting exemplary embodiments of the present invention, wherein like reference numerals represent similar parts of the present invention throughout the several views.

BRIEF DESCRIPTION OF THE DRAWING

In the accompanying drawings:

FIG. 1 is a sectional view showing the structure of a light-emitting device in the example set forth below;

FIG. 2A is a sectional schematic illustration of a second contact layer and an electrode layer before heat treatment;

FIG. 2B is a sectional schematic illustration of the second contact layer and the electrode layer after heat treatment; and

FIG. 3 is a graph showing distribution of elements in the second contact layer after heat treatment analyzed by Auger Electron Spectroscopy (AES);

FIG. 4 is a sectional schematic illustration showing the flow of electric current through the electrode pad, the electrode layer, and the second contact layer; and

FIGS. 5A and 5B are sectional views showing structure of electrode pads in the prior art.

DETAILED DESCRIPTION OF EXEMPLARY EMBODIMENTS

The present invention will be more fully understood by reference to the following example.

Example

FIG. 1 shows a sectional view of a light-emitting device 100 made of Group III nitride compound semiconductor which satisfies the formula: $Al_xGa_yIn_{1-x-y}N$, wherein $0 \leq x \leq 1$, $0 \leq y \leq 1$, and $0 \leq x+y \leq 1$.

The device 100 has a sapphire substrate 1. An AlN buffer layer 2 having a thickness generally of 0.05 μm was formed on the sapphire substrate 1. A silicon (Si) doped gallium nitride (GaN) layer 3 of n^+-type, having a thickness generally of 4.0 μm and having an electron concentration of $2 \times 10^{18}/cm^3$, was formed on the AlN buffer layer 2. An Si-doped GaN layer 4, having a thickness generally of 0.5 μm and having an electron concentration of $5 \times 10^{17}/cm^3$, was formed on the n^+-layer 3. A zinc (Zn) and Si doped emission layer 5, comprising of $In_{0.20}Ga_{0.80}N$ and having a thickness generally of 100 nm, was formed on the n-layer 4. Respective impurity concentrations of Zn and Si doping were $5 \times 10^{18}/cm^3$. An Mg-doped cladding layer 6 of p-type conduction. comprising of $Al_{0.09}Ga_{0.92}N$ and having a thickness generally of 100 nm. was formed on the emission layer 5. Impurity concentration doped into the cladding layer 6 was $5 \times 10^{19}/cm^3$ and its hole concentration was $2 \times 10^{17}/cm^3$. An Mg-doped first contact layer 71, comprised of GaN and having a thickness generally of 200 nm, was formed on the p-type cladding layer 6. Impurity concentration doped into the first contact layer 71 was $5 \times 10^{19}/cm^3$ and its hole concentration was 3 x

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$10^{17}/cm^3$. An Mg-doped second contact layer 72, comprised of GaN and having a thickness generally of 50 nm, was formed on the first contact layer 71. Impurity concentration doped into the second contact layer 72 was 1 x $10^{20}/cm^3$ and its hole concentration was 6 x $10^{17}/cm^3$.

A transparent electrode layer 8 was formed on the second contact layer 72. The electrode layer 8 has a double layer structure, comprising a first electrode layer 81 formed on the second contact layer 72 and a second electrode layer 82 formed on the first electrode layer 81. The electrode layer 81 was made of nickel (Ni) and had a thickness generally of 25 Å. The electrode layer 82 was made of gold (Au) and had a thickness generally of 60 Å.

An electrode pad 9 is formed on some portion of the electrode layer 8 and another electrode pad 10 formed on some portion of the n^+-layer 3. The electrode pad 9 has a triple layer structure, comprising a first metal layer 91, a second metal layer 92, and a third metal layer 93. The first metal layer 91 was made of Ni and had a thickness generally of 1000 Å. The second metal layer 92 was made of Au and had a thickness generally of 1.5 μm. The third metal layer 93 was made of aluminum (Al) and had a thickness generally of 300 Å. The electrode pad 10 was made of aluminum (Al). An protection layer 11 made of silicon oxide (SiO_2) covered the surface of the device 100 exposing some portion of the electrode pads 9 and 10 for wire bonding, as windows 9A and 10A, respectively.

A method for manufacturing the LED 100 is explained hereinafter.

Each layer, from the buffer layer 2 to the second contact layer 72, were formed on the sapphire substrate 1

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by gaseous phase epitaxial growth, called metal organic
vapor phase deposition (hereinafter MOVPE).

The gases employed in this process are ammonia (NH_3),
a carrier gas (H_2), trimethyl gallium ($Ga(CH_3)_3$)
(hereinafter TMG), trimethyl aluminum ($Al(CH_3)_3$)
(hereinafter TMA), trimethyl indium ($In(CH_3)_3$) (hereinafter
TMI), silane (SiH_4), diethyl zinc ($Zn(C_2H_5)_2$) (hereinafter
DEZ), and biscyclopentadienyl magnesium ($Mg(C_5H_5)_2$)
(hereinafter CP_2Mg).

The single crystalline sapphire substrate 1 has a
thickness of about 100 μm to 400 μm. After having its main
surface 'a' cleaned by an organic washing solvent and heat
treatment, the sapphire substrate 1 was placed on a
susceptor in a reaction chamber for the MOVPE treatment.
Then the sapphire substrate 1 was baked at 1100 °C by H_2
vapor fed into the chamber at a flow rate of 2 liter/min.
under normal pressure for a period of 30 min.

An AlN buffer layer 2, having a thickness of about
0.05 μm, was formed on the main surface 'a' of the baked
sapphire substrate 1 under conditions controlled by
lowering the temperature in the chamber to 400 °C, keeping
the temperature constant, and concurrently supplying for a
period of 90 sec. H_2 at a flow rate of 20 liter/min., NH_3
at 10 liter/min., and TMA at 1.8×10^{-5} mol/min.

An Si-doped GaN layer, having a thickness of about 4.0
μm, was formed on the buffer layer 2, as an n^+-layer 3 of
high carrier concentration with a Si concentration of about
$4 \times 10^{18}/cm^3$ and an electron concentration of about $2 \times 10^{18}/cm^3$, under conditions controlled by keeping the
temperature of the sapphire substrate 1 at 1150 °C and
concurrently supplying for 40 min. H_2 at a flow rate of 20

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liter/min., NH_3 at 10 liter/min., TMG at 1.7 x 10^{-4} mol/min., and silane diluted to 0.86 ppm by H_2 at 20 x 10^{-8} mol/min.

An Si-doped GaN layer, having a thickness of about 0.5 μm, was formed on the n^--layer 3, as an n-type layer 4 with a Si concentration of about 1 x 10^{18}/cm^3 and an electron concentration of about 5 x 10^{17}/cm^3, under conditions controlled by keeping the temperature of the sapphire substrate 1 at 1100 °C and concurrently supplying for 30 min. or less H_2 at a flow rate of 20 liter/min., NH_3 at 10 liter/min., TMG at 1.12 x 10^{-4} mol/min., and silane diluted to 0.86 ppm by H_2 at 10 x 10^{-9} mol/min.

An $In_{0.20}Ga_{0.80}N$ layer, having a thickness of about 100 nm, was formed on the n-type cladding layer 4 as emission layer 5 with respective Si and Zn concentrations of about 5 x 10^{18}/cm^3 under conditions controlled by keeping the temperature of the sapphire substrate 1 at 800 °C and concurrently supplying for 30 min. H_2 at a flow rate of 20 liter/min., NH_3 at 10 liter/min., TMG at 0.2 x 10^{-4} mol/min., TMI at 1.6 x 10^{-4} mol/min., and silane diluted to 0.86 ppm by H_2 at 10 x 10^{-8} mol/min.

An Mg-doped $Al_{0.08}Ga_{0.92}N$ layer, having a thickness of 100 nm and serving as a p-type cladding layer 6, was formed on the emission layer 5 under conditions controlled by keeping the temperature of the sapphire substrate 1 at 1100 °C and concurrently supplying for 6 min. H_2 at a flow rate of 20 liter/min., NH_3 at 10 liter/min., TMG at 1.12 x 10^{-4} mol/min., TMA at 0.47 x 10^{-4} mol/min., and CP_2Mg at 2 x 10^{-5} mol/min. The resistivity of the cladding layer 6 was 10^8 Ω·cm or more, exhibiting insulating characteristics. The impurity concentration of Mg doped into the cladding

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layer 6 was $5 \times 10^{19}/cm^3$.

An Mg-doped GaN layer, having a thickness about 200 nm and serving as a first contact layer 71, was formed on the cladding layer 6 under conditions of keeping the temperature of the sapphire substrate 1 at 1100 °C and concurrently supplying for 1 min. H_2 at a flow rate of 20 liter/min., NH_3 at 10 liter/min., TMG at 1.12×10^{-4} mol/min., and CP_2Mg at 2×10^{-5} mol/min. The resistivity of the first contact layer 71 was $10^8 \Omega \cdot cm$ or more, exhibiting insulating characteristics. The impurity concentration of Mg doped into the first contact layer 71 was $5 \times 10^{19}/cm^3$.

An Mg-doped GaN layer, having a thickness of about 50 nm and serving as a second contact layer 72, was formed on the first contact layer 71 under conditions of keeping the temperature of the sapphire substrate 1 at 1100 °C and concurrently supplying for 3 min. H_2 at a flow rate of 20 liter/min., NH_3 at 10 liter/min., TMG at 1.12×10^{-4} mol/min., and CP_2Mg at 4×10^{-5} mol/min. The resistivity of the second contact layer 72 was $10^8 \Omega \cdot cm$ or more, exhibiting insulating characteristics. The impurity concentration of Mg doped into the first contact layer 71 was $1 \times 10^{20}/cm^3$.

Then, electron rays were uniformly irradiated into the second contact layer 72, the first contact layer 71, and the cladding layer 6 using a reflective electron beam diffraction device. The irradiation conditions were set at 10 kV for the accelerating voltage, 1 μA for the sample current, 0.2 mm/sec. for the speed of the beam scanning, 60 μmφ for the beam aperture, and at 5.0×10^{-5} Torr vacuum. This irradiation changed the insulative three layers, the

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second contact layer 72, the first contact layer 71, and the cladding layer 6, to each be a p-type conductive semiconductor with respective hole concentrations of $6 \times 10^{17}/cm^3$, 3×10^{17}, and $2 \times 10^{17}/cm^3$ and respective resistivities of $2 \Omega \cdot cm$, $1 \Omega \cdot cm$, and $0.7 \Omega \cdot cm$. As a result, a wafer with a multiple layer structure was obtained.

A titanium (Ti) layer of about 2000 Å in thickness was formed on the second contact layer 72. A nickel (Ni) layer of about 9000 Å in thickness was formed on the Ti layer. Then, a photoresist layer was laminated on the Ni layer and a portion of the photoresist layer where an electrode pad 10 is formed was removed by photolithography. Utilizing the remaining photoresist layer as a mask, the exposed portion of the Ti layer and the Ni layer were etched by use of an acid etching liquid. Then, the remaining photoresist layer was removed. Utilizing the remaining Ti and Ni layers as a mask, the exposed portion of the layers from the second contact layer 72 down to the n-layer 4 were etched by reactive ion etching with gases containing chlorine. As a result some portion of the n^+-layer 3 was exposed. The remaining Ti and Ni layers on the second contact layer 72 were then removed by use of an acid etchant.

An electrode layer 8 with a double layer structure is formed as follows.

(1) A photoresist layer 12 was uniformly laminated on the entire sample. A portion of the photoresist layer 12 where the electrode layer 8 is selected to be formed was removed in, for example, nearly a square shape so as to form a window 12A.

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(2)   A first electrode layer 81, comprised of Ni and having a thickness generally of 25 $\overset{\circ}{A}$, was uniformly deposited in the window 12$\overset{\circ}{A}$ formed on the exposed part of the second contact layer 72 and on the photoresist layer 12 under a high vacuum condition of about 10^{-7} Torr in a deposition chamber.

(3)   A second electrode layer 82, comprised of Au and having a thickness generally of 60 $\overset{\circ}{A}$, was uniformly deposited on the first electrode layer 81 as shown in FIG. 2A.

(4)   After removal of the wafer from the chamber, portions of the Ni and Au layer that had been deposited on the photoresist layer 12 were removed by a lift-off method. Namely, the photoresist layer 12 and some portion of the Ni and Au layer thereon were removed at the same time. As a result, the transparent electrode layer 8, having a double layer structure comprising the Ni electrode layer 81 and the Au electrode layer 82, was obtained.

(5)   Then, another photoresist layer was uniformly laminated on the entire wafer. A portion of the photoresist layer was removed where the electrode pad 9 with a triple layer structure is to be formed, thereby forming, for example. a window.   Then, Ni. Au. and Al layers, respectively having a thickness of 1000 $\overset{\smile}{A}$, 1.5 μm, and 300 $\overset{\circ}{A}$, were successively and uniformly formed on the exposed portion of the Au electrode layer 82 and the photoresist layer in the reaction chamber. The wafer was then removed from the chamber, and the photoresist layer was removed by a lift-off method. which can be the same method used to form the electrode 8. As a result, the electrode pad 9 comprising of a first metal layer 91 made

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of Ni, a second metal layer 92 made of Au, and the third
metal layer 93 made of Al, was obtained. An electrode pad
10 made of Al was formed for the n^+-layer by vapor
deposition.

(6) The wafer was then returned to the chamber for a
process of heat treatment. After the chamber was evacuated
to less than 1 m Torr, and then filled with nitrogen (N_2)
to atmospheric pressure and closed, heat treatment was
carried out for a period of time ranging generally from
about several seconds (more than two) to 10 min. under
condition controlled by lowering the temperature to the
range of about 400 °C to 700 °C. Hydrogen (H_2), helium
(He), nitrogen (N_2), oxygen (O_2), neon (Ne), argon (Ar),
and krypton (Kr) or any combinations of these gases can be
used as the gas for filling the chamber. The chamber may
be evacuated in the range of 1 m Torr to more than
atmospheric pressure.

As a result of the heat treatment, the element of the
second electrode layer 82, for example, Au, penetrated
through the first electrode layer 81 and diffused into the
second contact layer 72, which comprised p GaN, thereby
forming an alloy of Au and p-GaN. For example, as shown in
FIGS. 2A and 2B, the vertically distribution of Au and Ni
before heat treatment (FIG. 2A) was reversed after heat
treatment (FIG. 2B). However, this reversal phenomenon
could not be observed at some portion of the electrode
layer 8 which was under the electrode pad 9. As a result,
the reversal of Ni and Au occurred in the portion of the
electrode layer 8 where the electrode pad 9 was not formed
thereover as shown in FIG. 4.

FIG. 3 is a graph showing the distribution of Au, Ni,

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Ga, and N in the second contact layer 72 as analyzed by
Auger electron spectroscopy (AES). Around from the surface
of the second contact layer 72 and to about 3 nm down from
its surface, the concentration of Ni was higher than that
of Au. However, the concentration of Au became higher than
that of Ni at a depth of more than about 3 nm from the
surface of the second contact layer 72. Thus, the element
Au penetrated through the first electrode layer 81 and deep
into the second contact layer 72 with a high concentration
to a depth of about 9 nm from its surface. As a result, an
alloy of GaN and Au was formed in the second contact layer 72.

The reversal of the element distribution appears to be
caused by the fact that the element of the first electrode
layer 81 has an ionization potential that is relatively
lower than that of the second electrode layer 82. By using
the method discussed above, the element of the first
electrode layer 81 moves up towards the surface of the
second electrode layer 82 and thus, the element of the
second electrode layer 82 moves down and penetrates through
the first electrode layer 81 into the GaN layer thereby
forming an alloy of GaN and Au. Since the element of the
second electrode layer 82 has an ohmic characteristic
better than that of the first electrode layer 81. the alloy
formed of GaN and Au enhances the ohmic characteristics of
the electrode to the device 100. Further, since the
element of the first electrode layer 81 which has a
relatively lower ionization potential than that of the
second electrode layer 82 is more reactive than that of the
second electrode layer 82, the element of the first
electrode layer 81 can be strongly connected to the Group
III nitride compound semiconductor device. As a result,

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the adhesive strength between the electrode layer 8 and the device 100 is improved.

Alternatively, at least one of palladium (Pd), iridium (Ir), and platinum (Pt) can be used instead of, or in addition to, gold (Au) as the element of the second electrode layer 82. At least one of iron (Fe), copper (Cu), chromium (Cr), tantalum (Ta), vanadium (V), manganese (Mn), aluminum (Al), and silver (Ag) can be used as the element of the first electrode layer 81 in stead of, or in addition to, nickel (Ni).

Further, an element that has an occlusion characteristic with respect to hydrogen (H) may be selected as the first electrode layer 81. An electrode layer 81 with this characteristic occludes H from the surface layer of the device that is formed beneath the first electrode layer 81, and thus, improves the crystallinity of the surface layer.

Then, a silicon oxide film (SiO_2), serving as a protection film 11, was uniformly formed on the entire sample by electron beam vapor deposition. Through processes including laminating a photoresist layer, patterning by photolithography, and removing some portions of the protection film 11 by wet etching, windows 9A and 10A were formed in, for example, nearly a square shape. Electrode pads 9 and 10 were respectively formed in windows 9A and 10A. The remaining photoresist layer was then removed.

Since the adhesive strength between the third metal layer 83 made of Au and the protection film 11 is strong, etching liquid is prevented from permeating therebetween. The portion of the protection film 11 covered with the

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photoresist layer remained unetched and accordingly sides
of the windows 9A and 10A remain unetched horizontally. As
a result, the protection film 11 completely and fully
protected the sides of the first metal layer 91, the second
metal layer 92, and the third metal layer 93.

Alternatively, one of Ni and Ti may be selected as an
element of the third metal layer 93 that has adhesion
strength to the protection film 11 which is stronger than
that of the second metal layer 92, or Au. As an alternate,
silicon nitride (Si_3N_4) may be used as a material of the
protection film 11.

Al is preferable as the material of the third metal
layer 93. Similar to the elements of the electrode layer
8, a reversal in the distribution of the elements of the
metal layer 9 was observed. The Ni of the first metal
layer 91 moved up through the second metal layer 92 and
partly appeared to its surface. When Al was used as the
material of the third metal layer 93, the Ni of the first
metal layer 91 did not appear through the third metal layer
93. In contrast, however, the element of the first metal
layer 91 appeared to and made patches on surface of the
third metal layer 93 when each of Ni and Ti was used as the
material of the third metal layer 93.

The wafer treated with the above-mentioned process was
divided or diced to form separate chips or elements
including the device 100 as shown in FIG. 1.

FIG. 4 shows the flow of electric current through the
electrode pad 9, the electrode layer 8, and the second
contact layer 72. Under the electrode pad 9, because Ni is
in direct contact with the second contact layer 72, the
electrode layer 8 has a higher contact resistance and

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electric current flows through other parts of the electrode layer 8 with a lower contact resistance where Au is in direct contact with the second contact layer 72. Accordingly, electric current does not flow under the electrode pad 9 where emitted light would be shielded thereby even if there are any emission and electric current is allocated to other parts where emitted light extends to outside of the device 100. Consequently, an effective current density is enhanced and, thus, luminous efficiency is improved.

The obtained device 100 was found to have a luminous intensity of 2000 mcd and a peak wavelength of 450 nm in the luminous spectrum at a driving current of 20 mA. Luminous intensity of the device 100 of the present invention doubled compared with that of a conventional device.

When improving luminous efficiency is a priority, the electrode pad 9 may have a single layer made of one of Ni, Au, and Al or a double layer made of two of Ni, Au, and Al. Further, the protection film 11 may not be necessary when improving luminous efficiency is a priority.

The thickness of the first electrode layer 81 should preferably be about 5 Å to 200 Å. When the first electrode layer 81 is thinner than 5 Å, its adhesive strength becomes weak. When it is thicker than 200 Å, its transparency worsens.

The thickness of the second electrode layer 82 should preferably be about 5 Å to 200 Å. When the second electrode layer 82 is thinner than 5 Å, its contact resistance becomes high. When it is thicker than 200 Å, its transparency becomes worsen.

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The thickness of the first metal layer 91 should preferably be about 20 Å to 5 μm. When the first metal layer 91 is thinner than 20 Å, its adhesive strength becomes weak. When it is thicker than 5 μm, it takes too much time to form.

The thickness of the second metal layer 92 should preferably be about 100 Å to 5 μm. When the second metal layer 92 is thinner than 100 Å, its reliability for wire bonding is lowered. When it is thicker than 5 μm, it takes too much time and cost to form.

The thickness of the third metal layer 93 should preferably be about 10 Å to 5 μm. When the third metal layer 93 is thinner than 10 Å, its adhesive strength becomes weak and it is unable to prevent the sides of the protection film 11 from being etched. When it is thicker than 5 μm, it takes too much time to form. Further, when one of Ni and Ti is used as the material of the third metal layer 93, its thickness should preferably be about 10 Å to 500 Å. When it is thicker than 500 Å, reliability for wire bonding is lowered.

In the above embodiment, the electrode pad 9 was formed on the electrode layer 8. Alternatively, the electrode pad may be formed directly on a p-type group III nitride compound semiconductor layer.

While the invention has been described in connection with specific exemplary embodiments, it is to be understood that the invention is not to be limited to the disclosed embodiments. Rather, the present invention is intended to include various modifications and equivalent arrangements as those that are within the spirit and scope of the appended claims.

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